A New Method for the Calculation of the Equivalent Inductances of Coplanar Waveguide Discontinuities

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ABSTRACT

Capacitive and inductive model parameters of coplanar waveguide discontinuities are calculated using the quasistatic three-dimensional finite difference method (3D-FDM). The equivalent inductances are derived from the magnetic field distribution in the coplanar slots, which is determined by solving the Laplacian equation for the inverse structure (i.e replacing the conductors with slots and vice versa). The method is applied to coplanar air bridge T-junctions and the results are compared with measurements. The influence of different types of air bridges are also investigated.

INTRODUCTION

Whereas a number of papers are published concerning the calculation of equivalent inductances of microstrip discontinuities [1]-[4], there are no publications known to the authors treating the equivalent inductances of coplanar waveguide discontinuities. In the case of microstrip, the equivalent inductances were derived from the current distribution on the conductors which is calculated using either the moment method [1] or Galerkin method [2]-[3]. The peresented paper is a new method for the calculation of the inductances of coplanar discontinuities using a three dimensional quasi-static finite difference method. The magnetostatic field distribution is derived from a magnetic scalar potential calculated from the solution of Laplacian equation for the "inverse" structure. The inverse structure is obtained by replacing the conductors with the slots and vice versa. The equivalent inductances are determined using different potential configurations coresponding to different current configurations at the discontinuity ports. The method is verified by measurements.

CALCULATION METHOD

Solving the Laplacian equation using 3D-FDM - The coplanar lines and a connected discontinuity (Fig. 1) are surrounded by a shield of electric and magnetic walls. The bounded region is divided into elementary boxes and a three dimensional finite difference expression is evaluated for the calculation of the potential at any point of the grid [5]. The metallized parts of the structure are held at constant potentials (Fig. 1) and the potential distribution inside the shielding is calculated using the "successive over relaxation method". In order to calculate the influence of the air- bridge as accurate as possible, the region under the bridge is discritized using a finer grid.

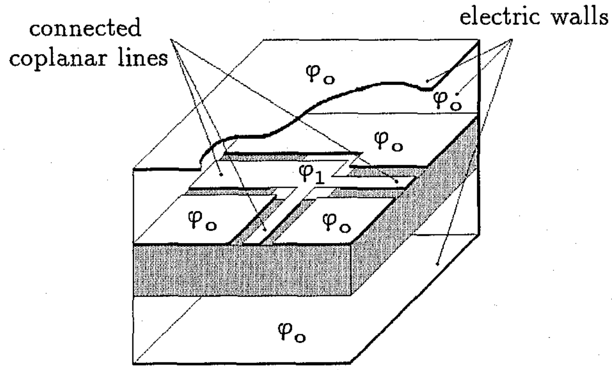

Fig. 1 - Potential configuration for the calculation of the discontinuity equivalent capacitance.

Calculation of the equivalent capacitance - The calculated potential distribution is used to determine the electostatic field distribution, which in turn is used to find the charge distribution on the conductors, leading to the total capacitance of the structure. An equivalent capacitance is evaluated as the difference between the total capacitance and the capacitance per unit length times the geometrical length of the connected coplanar lines [5].

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Calculation of the equivalent inductances - To describe the calculation method for the inductances used here, let us consider the structure in Fig. 2. The metallization thickness is assumed to be zero and the structure to be infinite in z-direction. Region I (conductors) serves as an electric wall and the Region II (slots) as a magnetic wall. The xz-plane is a plane of symmetry because the dielectric substrate dose not influence the magnetic field. It is thefore sufficient to consider only the space above the symmetry plane.

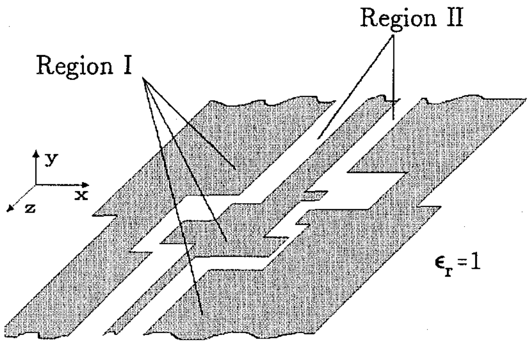


Fig. 2 - Schematic diagram for the description of the equivalent inductance calculation.

The electrostatic field **E** on the xz-plane must satisfy the following boundary conditions :

$\partial\varphi/\partial x = 0,$	$E_x = 0$	in Region I ,
$\partial\varphi/\partial z = 0,$	$E_z = 0$	in Region I ,
$\partial\varphi/\partial y = 0,$	$E_y = 0$	in Region II ,

where φ is the electrical potential. The condition rot**E**=0 in the space above the xz-plane leads to the Laplace equation:

$$\partial^2\varphi/\partial x^2 + \partial^2\varphi/\partial y^2 + \partial^2\varphi/\partial z^2 = 0 , \qquad \text{for} \quad y > 0 .$$

Let us consider now the inverse of the structure in Fig. 2, where the metallized parts of the structure are replaced by slots and vice versa. In this case the boundary conditions for the magnetostatic field **H** on the xz-plane are given by :

$\partial\psi/\partial x = 0,$	$H_x = 0$	in Region II ,
$\partial\psi/\partial z = 0,$	$H_z = 0$	in Region II ,
$\partial\psi/\partial y = 0,$	$H_y = 0$	in Region I ,

where ψ is the magnetic scalar potential. Here also rot**H**=0 in the space above the xz-plane and the Laplacian equation is satisfied for the magnetic scalar potential ψ i.e

$$\Delta\psi = 0 , \qquad y > 0 .$$

As it is shown above, the magnetic field in the coplanar slots can be calculated by solving the Laplace equation for ψ as it is done for φ. The integral of the magnetic field over the slot surface leads to the magnetic flux Φ, which is used for the calculation of the total inductance L of the structure.

$$\Phi = \int \mathbf{B}\cdot\mathbf{n}\,dA = \mu_0 \int H_y\,dA , \tag{1}$$

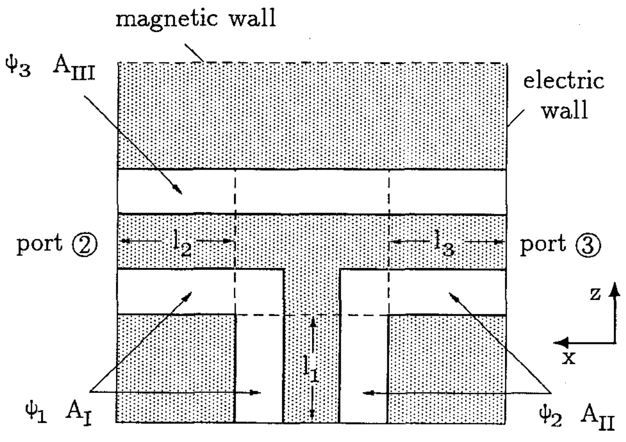
$$I = \oint \mathbf{H}\cdot d\mathbf{s} = \oint H_x\,ds , \tag{2}$$

$$L = \Phi / I . \tag{3}$$

The equivalent inductance is then evaluated from the difference between the total inductance and the inductance per unit length multiplied by the geometrical length of the connected coplanar lines.

RESULTS

The proposed method is applied to a colpanar T-junction and the equivalent parameters are calculated. Three various configurations of ψ (Fig. 3) are used in order to calculate the inductances ΔL_1, ΔL_2 and ΔL_3.



Fi. 3 - Magnetic scalar potential configurations for the calculation of the equivalent inductances of coplanar T-junction.

The current between ports ① an ② can be simulated using the following configuration for magnetic scalar potential ψ:

$$\left.\begin{matrix}\psi_1 = +1 \\ \psi_2 = -1 \\ \psi_3 = -1\end{matrix}\right\} \Rightarrow \Phi_{12} = \mu_0 \int_{A_I} H_y\,dA . \tag{4}$$

The equivalent inductances due to this curennt configuration can be calculated as :

$$\Delta L_1 + \Delta L_2 = \frac{\Phi_{12}}{4} - L_1' l_1 - L_2' l_2 \,, \qquad (5)$$

where L_1' and L_2' are the inductance per unit length of the lines connected to ports ① and ②. Analogously, for the simulation of the current between ports ① and ③ as well as the current between ports ② and ③, the following relations can be written:

$$\left.\begin{array}{l} \psi_1 = +1 \\ \psi_2 = -1 \\ \psi_3 = +1 \end{array}\right\} \Rightarrow \Delta L_1 + \Delta L_3 = \frac{\Phi_{13}}{4} - L_1' l_1 - L_3' l_3 \qquad (6)$$

$$\left.\begin{array}{l} \psi_1 = +1 \\ \psi_2 = +1 \\ \psi_3 = -1 \end{array}\right\} \Rightarrow \Delta L_2 + \Delta L_3 = \frac{\Phi_{23}}{4} - L_2' l_2 - L_3' l_3 \qquad (7)$$

Equations (5), (6) and (7) lead to the equivalent inductances of the T-junction. Fig. 4 shows the current distribution for two different current configurations on the ports of a symmetrical coplanar T-junction.

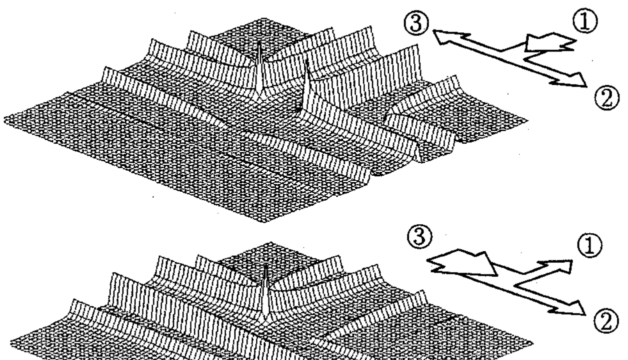
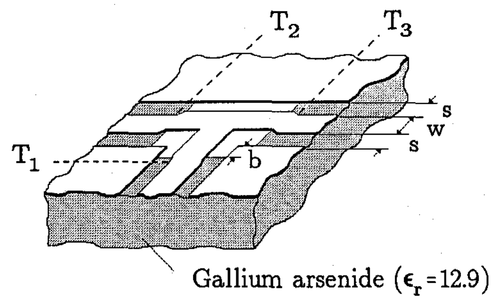
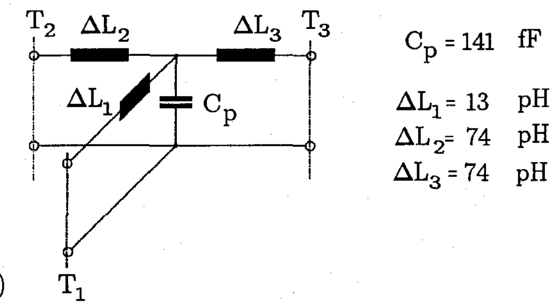


Fig 4. - Current distribution on conductors for a symmetrical coplanar T-junction

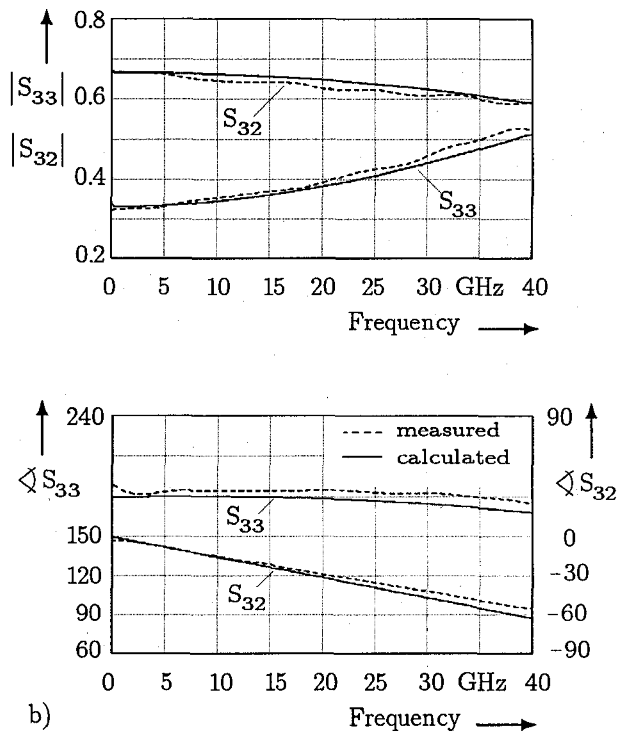
In order to verify the calculation method, the air bridge T-junction presented in [6] is fabricated on a GaAs substrate (h=400 μm) and the scattering parameters are calculated and measured up to 40 GHz. Fig. 5a shows the layout of the junction together with the calculated equivalent parameters. The scattering parameters of the junction are plotted in Fig. 5b together with the calculated results. Comparison of the results shows a good agreement even for the relatively high frequency of 40 GHz, where the discontinuity dimensions are in order of a quarter wavelength.



$w_1=w_2=w_3=75$ μm, $s_1=s_2=s_3=50$ μm,
b = 50 μm, bridge heigth = 2.5 μm .



a)



b)

Fig. 5 - Coplanar air bridge T-junction.
a) Layout and the equivalent circuit
b) Scattering parameters

For the investigation of the capacitive effect of air-bridges, the equivalent capacitance of the T-junction in Fig. 4a is calculated for different types of air bridges (Fig. 6a) and the reflection at port ③ is plotted in Fig. 6b. The influence of air bridges on equivalent inductances is not taken into account. The largest influence of the air bridge is found when type C is used. However, this type of air bridge has the advantage of suppressing the generation of higher modes (odd mode).

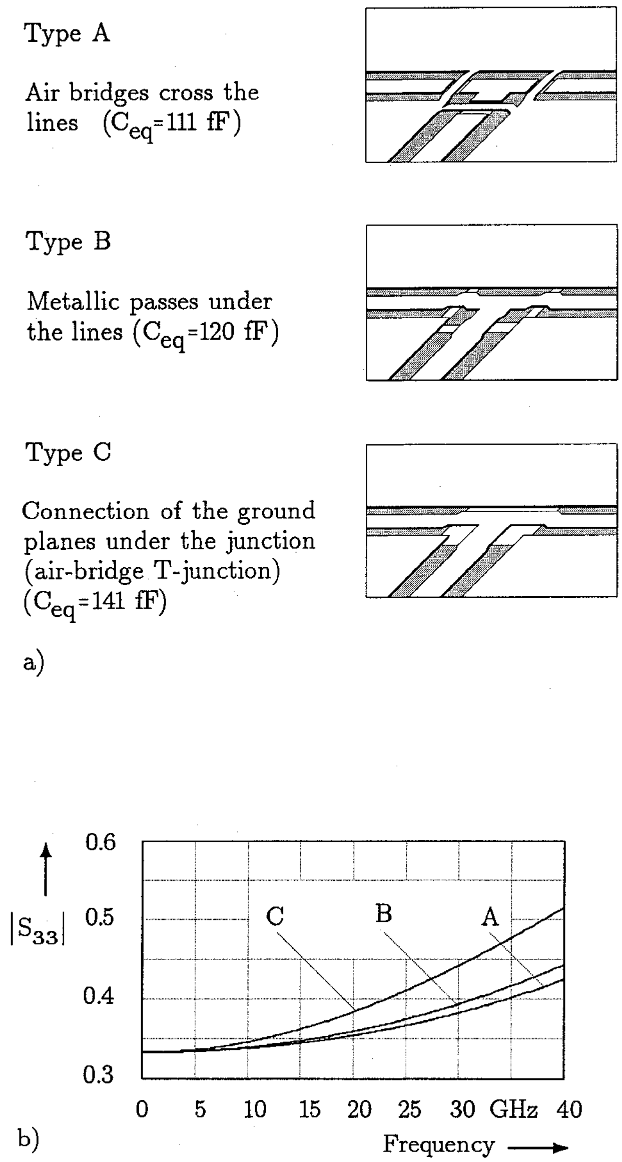


Fig. 6 - a) Different types of air bridges.
b) Influence of the air bridges on the reflection at port ③.

ADVANTAGES AND EXTENDED APPLICATIONS

The presented method is a simple and accurate alternative for the calculation of model parameters of discontinuities in coplanar waveguides. The method can also be applied to other coplanar lines such as coplanar strips (CS). More complicated structures like spiral inductors or spiral transformers can also be treated. The biggest advantage of the method is its small computation time (20-30 seconds for the presented junctions) and its relatively small memory storage requirement as a result of the non-equidistant discretization and the use of the iterative over relaxation method.

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